Main Injector Quadrupole Installer

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Abstract

The Main Injector (MI) accelerates protons which are used for neutrino and muon experiments as well as other R&D purposes at Fermilab. The MI is a two-mile long ring that is approximately 30 feet underground and consists of 344 dipole magnets and 208 quadrupole magnets. Quadrupole magnets are typically 8,000-12,000 lb plus the additional weight of the cradles holding them.

People get injured and spend too much time trying to get the positioning correct when removing or replacing a quadrupole The objective is to design and improve the methods for installing/removing quadrupole magnets in the X (in and out), Y (up and down), and Z direction (side to side). With a good understanding of the previous magnet installation equipment, design ideas can be formed to maximize safety and efficiency.

Background

There is already a machine that easily installs and removes the MI Dipole magnets, MI Dipole Installer. It uses double acting hydraulics in the X and Y direction. This will not work for a quadrupole magnet because of the allowable height under it.

MI Dipole Magnet being removed by the MI Dipole Installer

There is another machine that was once used to install and remove the magnets from the old Main Ring, the Energy Doubler Magnet Mover. Two of them are put under the 4 ton magnet. It uses a rack and pinion system in the X and Z direction. Teflon and cam rollers are used to minimize the coefficient of friction.

Energy Doubler Magnet Mover

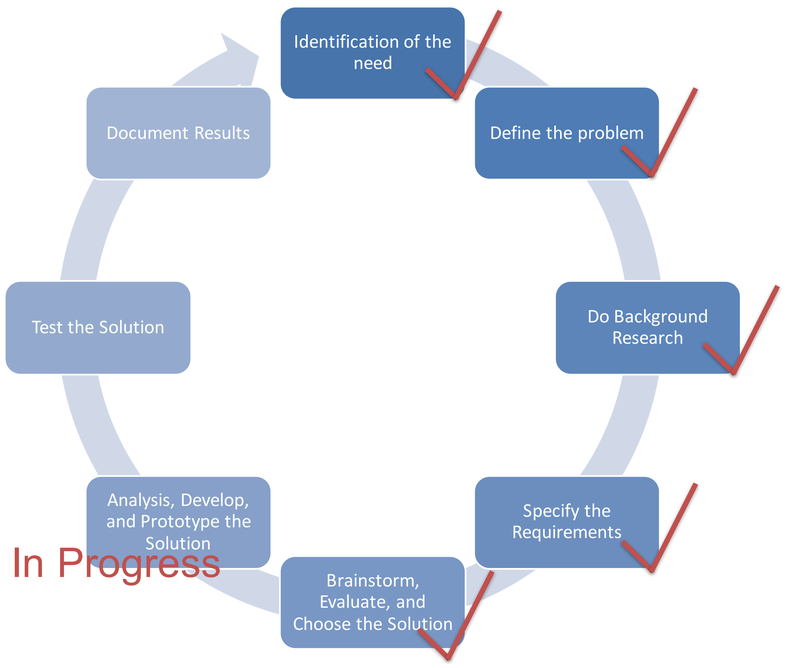
The current method for installing and removing the quadrupole magnets are come-alongs. Come-alongs are a hand operated winch with a ratchet used to pull objects. It gives an inaccurate positioning of the magnet. It can be unsafe when the cable on the come-along snap off or when it requires someone to push the magnet to position it properly.

MI Quadrupole Magnet being removed by a come-along

Specifications/Requirements

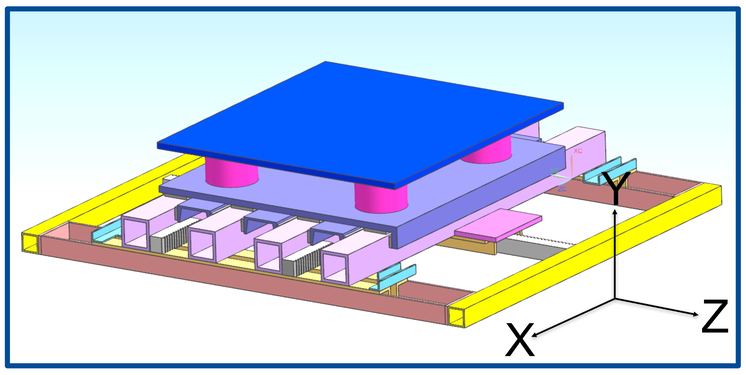
- Maximum load 13,061 lb.
- Can't exceed the height of 10.5 in.
- Can't exceed the length of 42.5 in.
- Translation in X, Y, Z
- Safe easy to operate
- Mobile

Design Process



Design Approach

The MI Dipole Installer and the Energy Doubler Magnet Mover both have great characteristics. By using the vertical hydraulic system from the MI Dipole Installer, quadrupoles can be raised and lowered. By applying the rack and pinion system from the Energy Doubler Magnet Mover, quadrupoles can be moved side to side and in and out. The design will have Teflon for easier gliding in the X direction and cam rollers for easier driving in the Z direction.



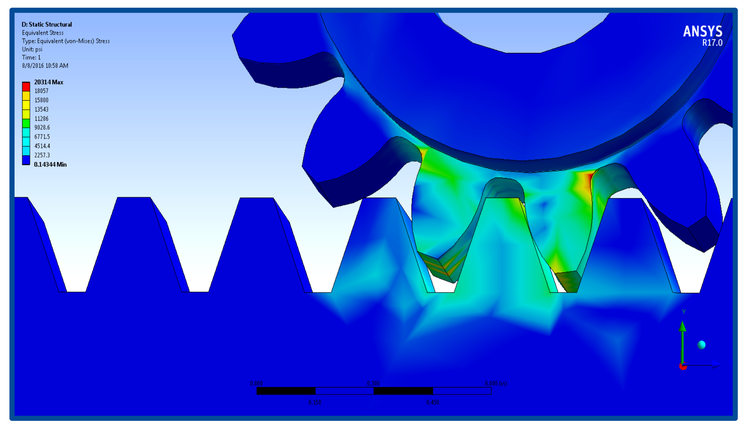
Main Injector Quadrupole Installer Design

Analysis/Results

The rack and pinion on the Energy Doubler Magnet Mover can support 8,700 lb. The new design needs to support a load of 13,061 lb.

The resulting output force of the gear is 724 lb. Considering the maximum weight of the magnet and cradle, the resistance force of each six cam roller is 10 lb. which does not exceed the output force, hence the cam rollers meets the requirements. With the maximum weight, the resistance force of the Teflon pads is 523 lb. which does not exceed the output force of the gear, therefore the Teflon is an appropriate material to use. When combining both the resistance forces of the cam roller and Teflon pad, it does not exceed the output force of the gear.

To further consider the strength of the gear, a stress analysis is performed. The gear must be able to handle a moment of 540 lb-in. and not exceed the yield strength of 24 ksi with an assumption of being pulled by a 3ft. socket wrench and a 15 lb force. Based on a Von Mises stress analysis, the stresses are strong enough to not exceed 24 ksi. This is confirmed by a rough hand calculation of 18 ksi. Therefore, the gear is sufficient for this design.



Von Mises stress analysis of the react and pinion

References

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2. Oshinowo, Babatunde O'Sheg, John A. Greenwood and Virgil Bocean. "Magnet Alignment For The Fermilab Main injector Project." 2016. *http://www.slac.stanford.edu/econf/C971013/papers/044.PDF.* Report